

Gold and climate change: An introduction



VISIT...

LANZAROTE
Caliente.COM

About the World Gold Council

The World Gold Council is the market development organisation for the gold industry. Our purpose is to stimulate and sustain demand for gold, provide industry leadership and be the global authority on the gold market.

We act when others do not, when change is essential and when the outcomes are at scale and sustainable. We will only intervene when we have the capacity to succeed and when we act aligned or in collaboration with leading market participants and stakeholders.

We work to protect and enhance trust and transparency in the market, while developing further understanding. Our involvement in developing appropriate pro-gold policies helps to create a fair and effective market and works towards ensuring universal access to gold. While our ambitions are extensive, our objective remains the same – to ensure a vibrant and growing gold market of ever greater relevance.

Based in the UK, with operations in India, the Far East and the US, the World Gold Council is an association whose members comprise the world's leading gold mining companies.

Contents

Introduction	01
Executive summary	03
Foreword	04
External commentary	06
Methodology	07
Gold demand, supply, and societal impact	09
Gold and greenhouse gas (GHG) emissions	10
The investment case for gold in a climate-change impacted world	13
Gold mining: taking action to reduce GHG emissions	18
Gold's role as a key component in low-carbon technologies	26
Conclusions and areas for future work	30
Appendix – detailed methodology	31
Glossary	33

Introduction

Climate change is one of the most significant threats facing the world today. There is robust scientific evidence that human activity has already caused warming of the climate system and other climate change impacts, including raised sea levels and ocean surface temperatures.

Recognising this threat, in December 2015 nearly 200 governments drafted the Paris Agreement, committing to hold the increase in the global average temperature to “well below 2°C above pre-industrial levels.”¹ Delivering the Paris Agreement requires all sectors of the global economy to work towards reducing greenhouse gas emissions. This is likely to transform the global economy, with some estimates placing the level of required investment at more than US\$1tn per year.²

It is natural, therefore, that investors consider the impact of these changes on their portfolios. In many cases, they are questioning what they can do to positively impact progress on climate change, noting the significant potential of the global investment community to support, and perhaps drive, societal change.

The gold industry recognises the importance of climate change and is committed to engaging in this dialogue and the transition to a low carbon economy.

Gold is an increasingly mainstream asset and a growing range of investors include it in their portfolios. Many investors are keen to understand the potential climate change impacts of their assets and, as gold’s role as a strategic asset continues to grow, there is a clear need for a better understanding of:

- the gold industry’s greenhouse gas (GHG) emissions profile – ‘gold’s carbon footprint’ – and how this compares with other sectors and assets
- the investment implications for current and potential holders of gold who are concerned about climate change
- the efforts already underway to reduce emissions and their likely impact
- how gold itself may play a role in improving energy efficiency and enabling renewable energy technologies, thus contributing to reduced GHG emissions.

“The risk climate change poses to businesses and financial markets is real and already present... climate-related risks and the expected transition to a lower-carbon economy affect most economic sectors and industries.”³

Michael Bloomberg, TCFD, 2017

1 European Commission, *International action on climate change*, 2015 https://ec.europa.eu/clima/policies/international/negotiations/paris_en

2 The IEA estimates US\$13.5Tn annual investment required to meet existing nationally determined contribution (NDC) pledges under the Paris Agreement to decarbonise the energy system between 2015 and 2030. In addition, the existing NDCs are not sufficient to fully meet the Paris Agreement commitments to reduce greenhouse gas emissions from energy, meaning further investment will be necessary. Beyond this, significant investment will be required to reduce greenhouse gas emissions from land use, land use change, and forestry. IEA, *Energy and Climate Change: World Energy Outlook Special Briefing for COP21*, 2015. https://www.iea.org/media/news/WEO_INDC_Paper_Final_WEB.PDF

3 TCFD, *“Final Report – Recommendations of the Task Force on Climate-related Financial Disclosures”*, 2017, <https://www.fsb-tcfd.org/publications/final-recommendations-report/>

This report sets out our initial research on gold and climate change. In preparing the report we faced several challenges. Relatively little consistent data exist on the GHG footprint of gold as comparatively few global assessments have been made. Furthermore, the complexity of the global gold supply chain, including the widely differing types of gold mining operations across the world, have contributed to a correspondingly wide range of emissions estimates in the sparse academic literature.

Working in collaboration with researchers at the Centre for Environmental Policy at Imperial College London, we have focused on GHG emissions associated with primary mine supply, because this is where most robust data is available. While data is still relatively scarce, this appears to be the segment of the gold supply chain that makes the most material contribution to gold's greenhouse gas footprint.

Our initial findings indicate that total GHG emissions from gold are significantly lower than other major products sourced primarily from mining, such as steel, aluminium and coal. Gold also has a far lower emissions intensity than most other metals when looked at per US\$ value

despite having a high emissions intensity on a mass basis. Importantly, the gold industry is already taking action to address the risks associated with climate change. Furthermore, as case studies in this report demonstrate, gold itself may play an important role in technologies that help facilitate a transition to a low carbon economy. Finally, emerging evidence suggests that in addition to providing financial diversification, an investment in gold may help reduce the carbon footprint of an investment portfolio while reducing investors' exposure to climate change risks. This is an important finding that requires further investigation.

The limited data and research on gold's global carbon footprint, coupled with the complexity of the gold supply chain and gold's diverse uses, mean our findings, and any conclusions we draw from them, are likely to be provisional and indicative. We acknowledge our analysis is very much a starting point, from which other work will hopefully flow. It is also intended to encourage further dialogue and engagement with gold industry stakeholders and communities, investors and policy-makers so that, collectively, we can help address the challenges presented by the risk of climate change.



Image courtesy of Goldcorp.

Executive summary

Gold is rare; as with other precious metals, a lot of ore is mined and processed to produce small amounts of pure metal. Consequently, gold production uses a lot of energy. On a per volume basis, therefore, it has a relatively high GHG intensity. However, our findings indicate that total GHG emissions from newly-mined gold are significantly lower than from other major products sourced primarily from mining, such as steel, aluminium and coal.

Gold is highly valuable. When analysed on a 'per US\$ value' basis, gold has the amongst the lowest emissions intensity of all metals and mined products.

Gold and the carbon footprint of investment portfolios

A wide range of investors now own gold and there is a growing need to understand how this might impact the carbon footprint of mainstream portfolios.

At the broadest level, an analysis⁴ of gold mining's emission levels in relation to its contribution to global GDP, suggests the industry's carbon footprint per US\$ is similar to that of the overall global economy.

And, although in its early stages, recent work⁵ looking at gold and equity investments suggests adding gold to a mainstream portfolio can, over time, reduce its overall carbon footprint.

Gold mining: taking action to reduce GHG emissions

Responsible gold mining companies take seriously their commitment to meet international standards, including reporting to the Carbon Disclosure Project (CDP). Importantly, action is already being taken by companies to address many of the risks associated with climate change. World Gold Council Member companies are seeking to reduce their carbon footprint through improvements in energy efficiency and, where possible, transition to low carbon energy sources.

Member initiatives vary greatly in type and scale, but they share common goals. These projects include a solar plant that will transform a mine's power consumption in Burkina Faso, mining company ventures to source hydroelectric power in Brazil and the Kyrgyz Republic, energy efficiency via award-winning air control automation in South Africa,

similarly lauded energy savings from optimised ventilation systems in Canada, and the world's first all-electric underground gold mine.

Gold and new low carbon technologies

In addition to industry steps to reduce GHG emissions, gold itself may play an important role in technologies that help facilitate the transition to a low carbon economy.

Of particular relevance in the context of mitigating climate change, gold in a nanoparticulate form has considerable potential in a range of applications that can help reduce GHG emissions. New technologies of note include:

- nanostructured gold catalysts to help convert CO₂ into useful fuels
- incorporating gold nanomaterials to enhance hydrogen fuel cell performance
- the inclusion of gold to improve photovoltaics and how the sun's energy is captured and utilised.

Conclusions and future work

We believe it important to achieve a better understanding of the scale and nature of gold's climate change impacts and our early stage findings on the GHG emissions of newly-mined gold have provided solid foundation for future work.

Our initial findings confirm that, whilst there is limited published data on gold's global carbon footprint, total GHG emissions from newly-mined gold are significantly lower than those from other major metals and mined products. When analysed on a 'per US\$ value' basis, gold has amongst the lowest emissions intensity of all metals and mined products.

Furthermore, recent research into how an investment in gold may potentially help reduce the carbon footprint of an investor's portfolio opens up a promising new area of study worthy of closer examination.

⁴ Emissions for gold per US\$ GDP relates to GVA estimates of the direct and indirect economic contributions to global GDP from gold mining activities (using 2013 data).

⁵ Baur & Oll, *The Role of Gold and the VIX in Investment Portfolios – A Financial and Sustainability Perspective* (2017).

Foreword



Paul Fisher
Chair, London Bullion
Market Association (LBMA)

In the space of under three years, climate change has gone from being a marginal, social issue, pursued by a minority of concerned activists, to being a mainstream political and financial issue. It has become a regular fixture on the agenda of the G20 and its Financial Stability Board, and is being actioned by governments, states, cities, corporates and financial and other regulators across the globe. Mark Carney's speech on 'The Tragedy of the Horizons' to Lloyds of London in September 2015, followed by the 21st Conference of Parties (COP 21) meeting in Paris later that year were notable tipping points.

.....
The risks to industry and to the financial sector from climate change are becoming well documented... For the gold industry, the transition risks and opportunities are less widely appreciated.
.....

As climate change has 'broken through' its political glass ceiling, other sustainability issues are following in its path, ranging from gender pay gaps and sexual harassment to the use of non-recyclable plastics.

The risks to industry and to the financial sector from climate change are becoming well documented. The most obvious are the physical risks from more extreme climate events: more floods, droughts, storms and so on. The data for the past 50 years or so shows patterns for such events rising on a trend, along with average global temperature and sea levels; trends which are accelerating in some cases. The full implications are only just being uncovered by industry and investors. Real estate investment is clearly at risk in many areas. But unexpected water shortages

will affect many industries, from agriculture and mining, to manufacturing and tourism. Many of the most popular beach resorts in Europe are in areas faced with the prospect of severe water shortages.

For the gold industry, the transition risks and opportunities are less widely appreciated. The economy will change as we move away from fossil fuels and environmentally unfriendly materials. For example, we know that the age of petrol/diesel cars is limited as cities such as Paris and London have already announced future dates for outright bans. Some large-scale renewable energy supplies are now cheaper than fossil fuel generated energy and relative costs are still falling sharply, as they are for electricity storage technologies. The economics will drive much of the transition, fuelled by consumer concerns, probably faster than the politics can follow. There will be new industrial processes, new goods, new services. The circular economy (continual re-use of materials) will gain in strength. The gold industry will need to adapt, both its mining operations and its target markets.

My own work in this field lies in a second strand of transition risk, that arising from policy change. At COP21 in Paris, 197 governments and authorities from around the world promised to take action to limit global warming to no more than two degrees (relative to the average before most of the world had industrialised: 1850-1900). Warming has already reached about 1.2 degrees and the trend seems remorseless with 2015-17 being the three warmest years in modern records.

But we haven't known precisely what governments were going to do to meet their promises until now, as the policies are starting to be announced. The FSB in 2017 published a report on Climate-related Financial Disclosures from a private-sector-led Task Force (the TCFD). That report has been endorsed by many leading governments, action has been started to include the recommendations in some national official reporting guidance. In March 2018 the European Commission published its action plan on sustainable finance, following the year-long work of a High Level Expert Group (on which I had the privilege to serve).

China is probably ahead of the rest of the world on policy changes, as it tries to reduce the horrendous pollution in its major cities. A number of global and regional financial centres are pursuing green finance as a growth opportunity. Many, many policy changes are likely around the world in the years to come. And those policies will affect industries and specific companies both positively and negatively.

The sustainability agenda provides major business opportunities as well as risks. The global economy is always changing, never static. If companies want to make money and survive they need to spot the growth areas and avoid becoming dependent on declining sectors. So they need to be ready to take up the sustainability challenges. Not only is reputation key to many businesses – and there are already legal risks for those who ignore Sustainability issues or make bad judgement calls on them – but research is now consistently showing that companies who score highly on ESG factors (Environmental, Social and Governance) produce better returns.

So two challenges to the gold industry, especially the mining side, are:

- 1 How to demonstrate that it is not part of the problem: for example, by committing to reduce carbon emissions it is responsible for, on a path consistent with limiting global warming to under two degrees in line with the Paris agreement; being efficient in water usage; and protecting/restoring the environment around mining operations.
- 2 How to be part of the solution: for example, by researching uses for precious metals in the new technologies that will underpin the transition.

To be successful, these issues should not just be embraced to meet Corporate Social Responsibility. They are hard-headed, financial and business issues which must be treated accordingly.

The LBMA is doing what it can to help, by improving its Responsible Sourcing Guidance, covering all precious metals, for refiners, and by alerting its members to the wider risks and opportunities whenever it can.

The WGC can play a major role in helping its members: encouraging the adoption of the TCFD recommendations would be a great initiative for example, including the setting of measurable targets for the industry, and individual firms, consistent with the two degree transition.

Energy use in the precious metals industry – both extraction and refining – although a small part of the total global economy, and producing high value products, is undeniably intensive. But that means that there are tremendous gains to be had from moving to cheaper, cleaner energy sources and more efficient production techniques. The best, most profitable companies are embracing these changes already.

The good news is that firms don't have to rely just on internal expertise. There are many organisations with the technical and policy knowledge quietly working behind the scenes to help firms – both individually and collectively – make progress, including several major UK universities, as shown by this report.

External commentary

Dr Jeremy Woods,
Prof Nick Voulvoulis,
Dr Onesmus Mwabonje
and Dr Gino Baudry,
Imperial College London

This report was reviewed by Dr Jeremy Woods, Prof Nick Voulvoulis, Dr Onesmus Mwabonje and Dr Gino Baudry from Imperial College London, facilitated by the College's consultancy company Imperial Consultants.

We are environmental scientists working in the Centre for Environmental Policy (CEP). CEP carries out Internationally relevant, cross-disciplinary, high-impact science, technology and policy research on climate change, environmental resources management, energy and sustainable transitions.

We recognise that calculating the gold industry's greenhouse gas (GHG) emissions is complex and time-consuming with publicly accepted methodologies yet

to be established. The gold sector uses a wide range of extraction and purification technologies, and extracts gold from ores with low purities compared to the other major metals. Gold is also a very high value material with an extremely long life. As a result, determining gold's carbon footprint remains challenging, being closely linked to questions of transparent and robust data availability, developing consistent system boundaries and standardised reporting methodologies.

The work presented in this report provides a best estimate range for gold's carbon footprint and is based on publicly available data and existing GHG emissions inventories, allowing a preliminary comparison with those of other major metals at the global scale. More importantly, this report marks a critical step for the gold industry, in raising awareness and developing protocols and guidance for gold companies seeking to measure and ultimately reduce their GHG emissions and risks associated with climate change. As environmental scientists, we are committed to helping the industrial transition to a low carbon future. Our involvement with the development of this report has aimed to support and critically challenge the analysis undertaken by the World Gold Council, to make sure that the methodology and estimates provided are both realistic and functional in guiding the industry's next steps.

Methodology

When looking at the GHG emissions of a product, organisation or process, it is important to make comparisons on a like-for-like basis.

Scope 1 – Direct GHG Emissions	Scope 2 – Indirect Electricity Emissions	Scope 3 – Other Indirect Emissions
GHG emissions occurring from sources owned or controlled by the organisation, e.g.: - emissions from combustion in owned or controlled boilers, furnaces or vehicles - emissions from chemical processes in owned or controlled equipment - emissions from land owned or controlled by the organisation.	GHG emissions at power plants generating electricity purchased by the organisation.	GHG emissions that occur as a consequence of the activities of the organisation, from sources not owned or controlled by it, e.g.: - emissions from third-party transport of purchased materials or finished goods - emissions from the use of products sold.

Source: The Greenhouse Gas Protocol

International standards on carbon footprinting⁶ set out a consistent approach to the assessment and comparison of emissions based on rigorously established, consistent and comparable boundaries that determine what is measured. These define three different ‘scopes’ for emissions.

In this report we have considered GHG emissions from the production process prior to gold entering the market as a finished product. This includes Scope 1 and Scope 2 emissions from mining, milling, concentrating and smelting, as well as the refining processes shown in **Figure 1**. Comparisons with other metals and mined products are made on the same basis. Emissions due to iron ore extraction are included within estimates of GHG emissions from steel production.

This report presents our current estimate of three measures related to GHG emissions of gold production on a worldwide basis:

- total GHG emissions from gold production (expressed in tonnes (t) of carbon dioxide equivalent, or CO₂e)

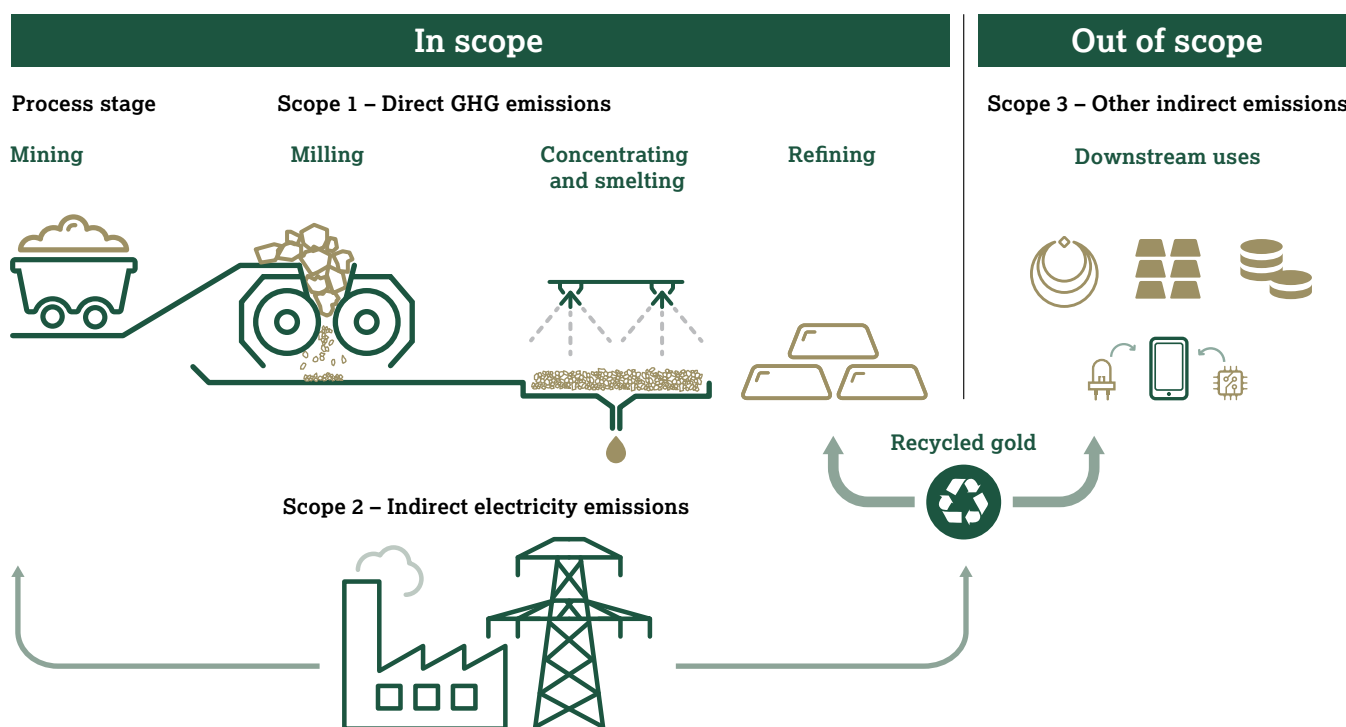
- GHG emissions intensity per unit mass: the mass of GHGs emitted to produce a given mass of product (for example, expressed in tonnes CO₂e per tonne product)
- GHG emissions intensity per unit value: the mass of GHGs emitted to produce a given value of product (for example, expressed in tonnes CO₂e per dollars’ worth of product).

Our approach to estimating these measures and comparing them with other products has been based on a thorough literature review and developed in discussion with experts at Imperial College London. Although a range of different estimates of GHG emissions intensities exists in the literature, compared to some sectors relatively little primary data is available. In order to ensure transparency and facilitate fair comparison, we also present a range showing the highest and lowest estimates we have found in the literature. Note that the highest estimate represents the emissions intensity from one particular country – China⁷ – rather than the global gold market as a whole.

Further details on the methodology can be found in **Appendix 1**.

⁶ World Business Council for Sustainable Development & World Resources Institute. *The Greenhouse Gas Protocol – A Corporate Accounting and Reporting Standard. Revised Edition*, 2015. www.ghgprotocol.org

⁷ See ‘Appendix – detailed methodology’ for further comment on the research (Chen et al. 2018) from which this estimate is drawn.

Figure 1: Gold supply chain and report focus

Downstream emissions and recycling

Given current data limitations we have chosen to focus on the carbon footprint of primary gold supply. We have not considered GHG emissions and related sustainability impacts from gold recycling or gold's main downstream end uses and applications – for example, in jewellery, investment and technology.

As noted, there is a lack of existing information related to GHG emissions from recycled gold and end uses. However, our emerging view, which requires further validation, is that these emissions are likely to be small in comparison to emissions from primary production. There is evidence that the refining stage of gold production represents less than 0.1% of the overall carbon footprint of primary gold production (see **Chart 3**).⁸ GHG emissions from gold recycling – essentially a process of re-refining – is therefore likely to be orders of magnitude lower than mine production.

As recycled gold typically contributes between 25-30% of annual world gold supply, this means that the overall GHG intensity of gold is likely to be lower, by a similar proportion, than estimated in this report.

We also believe that, in comparison with the GHG emissions from mining, milling, concentrating, smelting and refining processes, emissions from other downstream activities in the gold sector are likely to be very small and relatively immaterial in scale. This requires further research. We note that this is not the case for most other metals, which are processed further, and may form primary components of products with very substantial additional emissions. It is also not the case for fossil fuels, including coal, oil and gas, all of which generate significant GHG emissions on consumption.⁹

⁸ Norgate & Haque. *Using life cycle assessment to evaluate some environmental impacts of gold production*. *Journal of Cleaner Production*, Volume 29-30, 53, 2012.

⁹ Ibid.

Gold supply, demand, and societal impact

Annual demand for gold is met by a combination of newly-mined and recycled metal. Recycled gold now generally makes up between 25% and 30% of annual supply.

Mine production comes primarily from large-scale gold miners, many listed on public stock exchanges. An additional source of gold comes from artisanal and small-scale miners, operations that operate predominantly simplified forms of exploration and extraction.

The supply of gold from both mine production and recycling, as seen in **Chart 1**, contributes to the unique nature of the gold industry. Primary production creates significant value that typically remains in the host country.¹⁰ Strong evidence points to the catalysing effect of responsible gold mining; not only does it contribute to national GDP but it also encourages wider socio-economic development, particularly in developing countries.¹¹

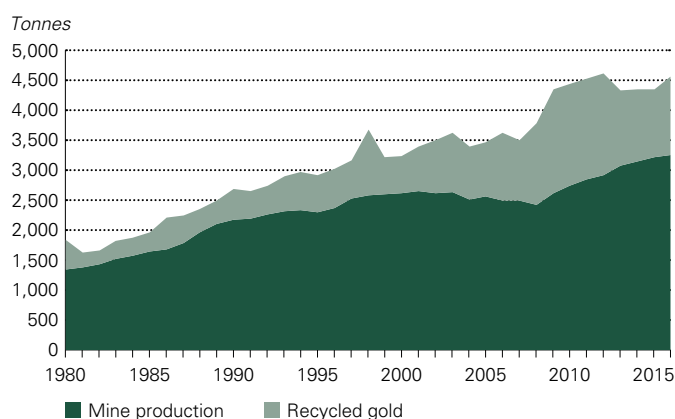
Recycling has a highly significant role, satisfying demand that cannot be met by newly-mined gold alone and demonstrating the circularity of the gold industry. Unlike many metals and natural resources, gold is not destroyed over time or by the act of consumption; nearly all the gold ever mined is still present and potentially available for re-use. Whilst newly-mined gold has averaged approximately 70% of total supply over the last 10 years, annual mine production has been consistently less than 2% of total stocks of above-ground gold.

The different nature of newly-mined and recycled gold entering the supply chain has interesting potential implications for gold's overall carbon footprint, a concept we start to explore in this report but which merits further consideration.

Gold is also distinct from most other metals and mined products in the diversity of its uses and sources of demand. While an examination of gold's downstream markets and their possible impacts on climate change are beyond the scope of this report, it is important to note that the market value of gold is a key consideration in our analysis and gold's enduring value is underpinned by the unique structure of the market and the diverse drivers of demand (see **Chart 2**).¹²

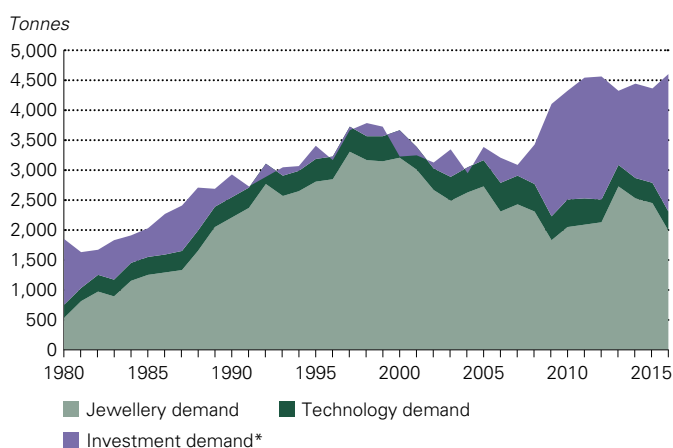
Whilst newly mined gold has averaged approximately 70% of total supply over the last 10 years, annual mine production has been consistently less than 2% of total stocks of above-ground gold.

Chart 1: Global gold supply



Source: GFMS, Thomson Reuters; Metals Focus; World Gold Council

Chart 2: Global gold demand



Notes: Data prior to 1995 may refer to fabrication demand. *Investment demand includes central bank purchases and sales, net ETF investment and OTC investment flows.

Source: GFMS, Thomson Reuters; Metals Focus; World Gold Council

¹⁰ World Gold Council. *Responsible Gold Mining and Value Distribution*, 2014. <https://www.gold.org/research/gold-mining-economic-contribution-value-distribution>

¹¹ Maxwell Stamp and World Gold Council. *The Social and Economic Impacts of Gold Mining*, 2015. <https://www.gold.org/research/social-economic-impact>

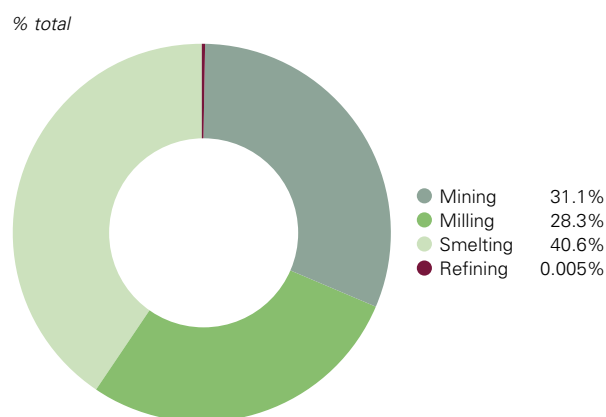
¹² For more information, see <https://www.gold.org/about-gold/gold-demand>

Gold and greenhouse gas (GHG) emissions

The processes involved in mining, milling, concentrating, smelting and refining gold all have potential to produce greenhouse gas emissions.

As illustrated in **Chart 3**, GHG emissions from gold are predominantly caused by mining, milling, concentrating and smelting. The reasons for this are driven by gold's geology. Gold is an extremely scarce element: ore grades (the amount of gold potentially extractable from a volume of rock) are typically in the range of 1 to 6 grams per tonne of rock. In comparison, a recent estimate suggested the global average mined copper ore grade is approximately 0.62% of Cu content, representing over 6kg of copper per tonne of ore.¹³ Furthermore, gold ore grades have declined over recent decades and fewer and fewer discoveries of ore bodies are able to be transformed economically from ore to metal. Such scarcity means a large amount of rock needs to be extracted and processed (mined, milled, concentrated, smelted and refined) to derive small volumes of pure gold, whereas for many 'base' or 'bulk' metals, large volumes of ore produce relatively large volumes of metal.

Chart 3: GHG footprint for gold by production stage



Source: Nawshad and Haque 2012, World Gold Council

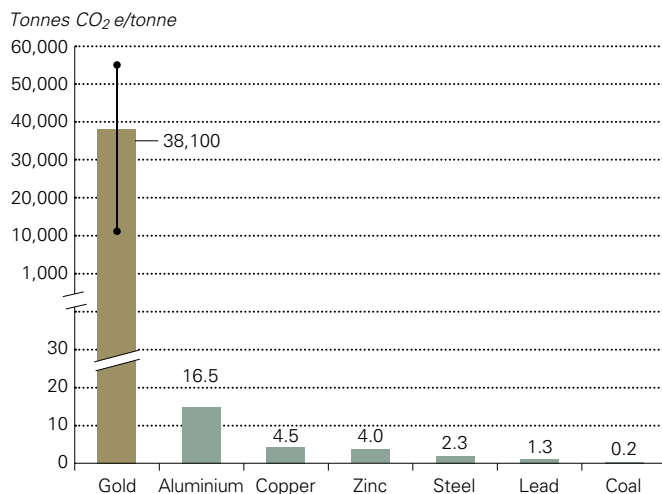


Image courtesy of Agnico Eagle.

¹³ Calvo et al., *Decreasing Ore Grades in Global Metallic Mining: A Theoretical Issue or a Global Reality?* *Resources*, 5, 4, 36, 2016.

The gold production process needs to use a relatively high level of energy to bring finished gold to market. Gold therefore has significantly higher GHG emissions intensity per tonne of finished product than other bulk metals (see **Chart 4**).

Chart 4: Emissions Intensity per unit mass



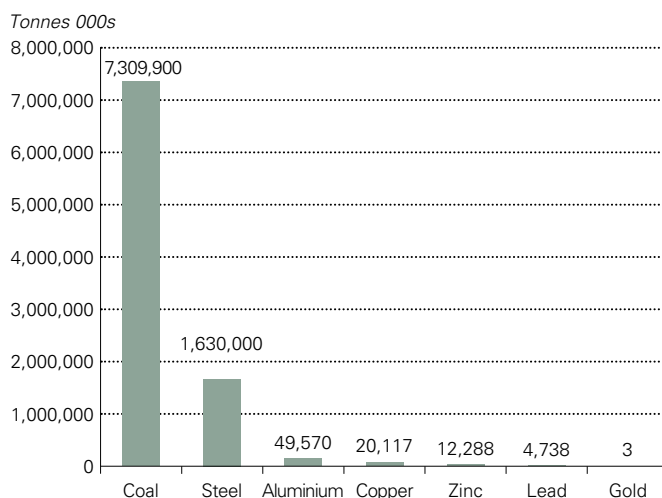
Note: Range values for gold are based on high and low estimates of the GHG emissions intensity per tonne of gold as reported in academic literature

Source: Metals Focus; S&P Global Market Intelligence; World Steel Association & EIU; World Gold Council

Emissions data collated from a range of academic studies and trade association reports

However, due to gold's scarcity, it is produced in far smaller quantities than other major mined products (see **Chart 5**).

Chart 5: Volume of annual production of major mined products

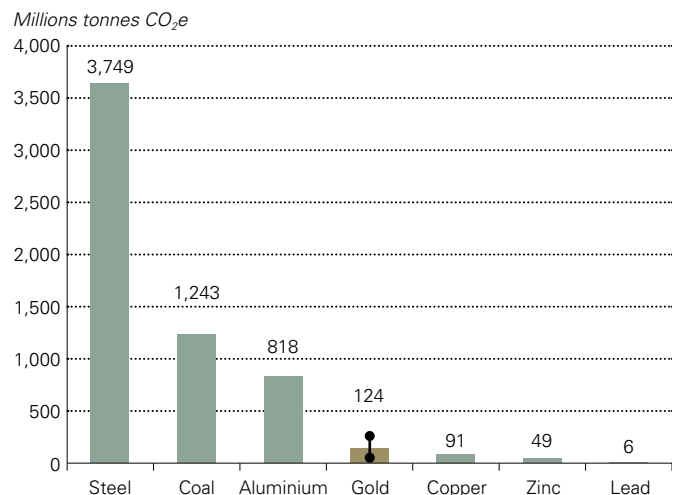


Based on 2016 data

Source: Metals Focus; S&P Global Market Intelligence; World Steel Association & EIU; World Gold Council

As a result, we estimate the total volume of GHG emissions related to global gold production to be significantly smaller than those from other major mined products, notably steel, aluminium and coal, but comparable to GHG emissions from copper and zinc (see **Chart 6**).

Chart 6: Total GHG emissions



Note: Range values for gold are based on high and low estimates of the GHG emissions intensity per tonne of gold as reported in academic literature

Production, based on 2016 data

Source: Metals Focus; S&P Global Market Intelligence; World Steel Association & EIU; World Gold Council

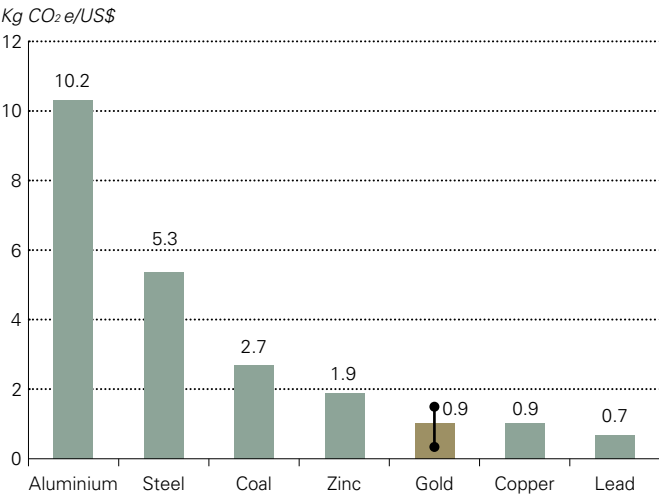
Emissions data collated from a range of academic studies and trade association reports.

Gold has amongst the lowest GHG emissions per dollar of the major mined products.

Gold is highly valuable. Along with other precious metals it is worth orders of magnitude more per tonne than other mined products; taken as a whole, the entire annual value of newly-mined gold is larger than almost all other metals and mined products, and smaller only than coal and steel. When analysed on a ‘per unit value’ basis, we estimate gold has amongst the lowest GHG emissions per dollar of the main mined products, materially lower than steel, aluminium and coal (see **Chart 7**). In other words, the volume of GHG emissions associated with a dollar spent on gold is lower than for a dollar spent on most other mined products.

Despite the relatively low emissions per value, it is recognised that existing gold mining operations do require significant amounts of energy in absolute terms. The industry is committed to reducing its energy usage and managing its energy to lower GHG emissions. Examples of action already being taken are presented later in this report. Further research is needed to establish a pathway consistent with the Paris accord of limiting the increase in average temperature to less than 2C. This is a challenge that the gold mining industry is collectively considering how best to respond to.

Chart 7: Emissions intensity per unit value



Note: Range values for gold are based on high and low estimates of the GHG emissions intensity per tonne of gold as reported in academic literature
Production, based on 2016 data
Source: Metals Focus; S&P Global Market Intelligence; World Steel Association & EIU; World Gold Council
Emissions data collated from a range of academic studies and trade association reports



The investment case for gold in a climate-change impacted world

Investors, asset owners and financial regulators are increasingly clear that climate change, and the global response to it, pose significant risks to – and opportunities for – companies and investors.

These include both direct physical risks and the impact of changes associated with the transition to the low-carbon economy.¹⁴

Physical risks: Impacts of extreme weather events (such as floods and cyclones) and long-term changes to weather and climate (such as precipitation patterns and rising sea levels).

Transition risks: Financial risks due to the structural shift to a low-carbon economy; likely to result in the revaluation of a large range of assets, driven by changes in policy, technology and economics.

Through initiatives such as the Principles for Responsible Investment, investors are increasingly demanding greater transparency from companies regarding their climate-related risks and corresponding strategies to mitigate those risks. To enable this, the G20-sponsored Task-Force on Climate-Related Financial Disclosures has established recommendations for disclosing clear, comparable and consistent information about the risks and opportunities presented by climate change. This will allow investors to assess which companies are most at risk from climate change, which are best prepared, and which are taking action.

The World Gold Council recognises the importance of these issues to investors and understands that they will be asking how the risks and opportunities presented by climate change apply to investing in gold. In order to contribute to this dialogue, this section of the report shares our initial analysis in response to the following questions:

- how does gold's carbon footprint compare to other investment opportunities?
- what is the likely impact of including gold on the carbon footprint of an investor's portfolio?
- how exposed is gold to climate-related risks and how does this compare to other asset classes?

“Asset owners see climate change as one of the most important long-term trends for investment and... they are taking action on this.”¹⁵

Principles for Responsible Investment,
Investor Action on Climate Change, 2017

¹⁴ For example see: The Bank of England, *The Bank's Response to Climate Change*, 2017, <https://www.bankofengland.co.uk/quarterly-bulletin/2017/q2/the-banks-response-to-climate-change> and Task Force on Climate related Financial Disclosures, Recommendations of the Task Force on Climate-Related Financial Disclosure – Final Report, 2017, <https://www.fsb-tcfd.org/publications/final-recommendations-report>

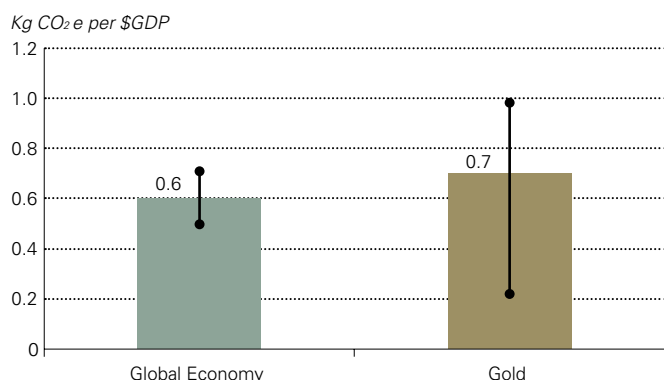
¹⁵ Principles for Responsible Investment, *“Investor Action on Climate Change,”* 2017. The Principles for Responsible Investment is a global investor initiative with over 1,100 signatories representing assets under management of over US\$70trn. www.unpri.org/pri/about-the-pri

How does gold's carbon footprint compare with other investment opportunities?

One of the primary objectives of this research has been to provide a better understanding of the carbon footprint of gold entering the market, while recognising that substantial further work is required to gain a more comprehensive picture of gold's impacts. As set out in the Gold and Greenhouse Gas (GHG) Emissions section of this report, our research indicates that per US\$ value, gold has a lower carbon footprint than all other major metals and mined products, including steel, aluminium and coal.

Potential investors in gold, however, are likely to be looking at a far wider range of opportunities well beyond mined commodities. To provide them with a broader context, we examined gold's GHG emission intensity as it relates to the wider global economy; specifically, we looked at what newly-mined gold's carbon footprint looks like when measured against the value the industry adds to global GDP, and how this compares with the average figure for the overall economy.

Chart 8: Emissions intensity of world economy compared with gold mining



Note: Emissions intensity for the global economy is represented per US\$GDP. Emissions intensity for gold is represented per US\$GVA, comprised of the direct and indirect economic contributions from gold mining activities. The range values for the global economy are based on low and high estimates as reported in international GHG inventories. The range values for gold are based on high and low estimates of the GHG emissions intensity per tonne of gold as reported in academic literature. We have used 2013 data for this comparison as this is the most recent year for which estimates for gold's contribution to the economy are available.

Source: WGC Analysis based on data from World Bank, Maxwell Stamp and World Gold Council (2015), Netherlands Environmental Agency (2014) and (2017), Haque & Norgate (2014), Norgate & Haque (2012)

Based on our current estimate of the emissions intensity of gold production, our assessment is that annual production of gold in 2013 emitted a total of c.117M tCO₂e and contributed US\$171bn to the world economy – giving a carbon intensity of 0.7 kg CO₂e/US\$GVA. In total, the world emitted c.48bn tCO₂e to generate US\$77tn GDP in 2013 – a carbon intensity of 0.6 kg CO₂e/US\$ GDP.¹⁶ This is depicted in **Chart 8**.

Initial research suggests that gold's GHG emissions intensity is comparable with that of the global economy as a whole.

Comparisons between specific sectors of the economy, such as gold production, and the global economy as a whole are difficult, not least due to challenges in ensuring the comparability and consistency of both economic and emissions data. These differing levels of uncertainty in the data at least partially explain why there is a wider range between our highest and lowest estimates of the GHG emissions intensity for gold than that for the wider economy.

What is the likely impact of including gold on the carbon footprint of an investor's portfolio?

We believe it is helpful for investors to be able to evaluate the GHG footprint of an investment in gold compared to an equivalent investment in other mainstream asset classes, such as equities. While limited research exists to date, recent work by Baur & Oll (2017)¹⁷ has begun to address this topic.

Using data reported by S&P Dow Jones Indices, Baur & Oll estimate the carbon footprint of an investment in the S&P 500 and in gold. For the S&P 500, they look at the total annual emissions of the companies in the index, and allocate these in proportion to the value of the investment relative to the total market capitalisation of the index.

¹⁶ Gold's contribution to GDP refers to GVA (gross value added), summarising the direct and indirect economic contributions from gold mining activities. GHG data from Netherlands Environmental Agency, Trends in Global CO₂ and total Greenhouse Gas Emissions, 2017, <http://www.pbl.nl/en/publications/trends-in-global-co2-and-total-greenhouse-gas-emissions>. Gold emissions intensity based on Haque & Norgate. The greenhouse gas footprint of in-situ leaching of uranium, gold and copper in Australia, Journal of Cleaner Production 84, 382, 2014; Norgate & Haque. Using life cycle assessment to evaluate some environmental impacts of gold production, Journal of Cleaner Production 29, 53, 2012.

¹⁷ Baur & Oll. *The Role of Gold and the VIX in Investment Portfolios – A Financial and Sustainability Perspective*, 2017. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3069283

To make a fair comparison between portfolio assets, Baur & Oll estimate the annual GHG emissions associated with a US\$1mn investment in the S&P 500 and gold. They calculate the annual GHG emissions associated with the S&P 500 are 2.05 billion tonnes, and a US\$1mn investment therefore equates to 111 tonnes. We have taken this approach and adapted it with updated and more granular data for gold, resulting in a wider range of estimates (as described in the Chart note, below, and in 'Appendix – further methodology').

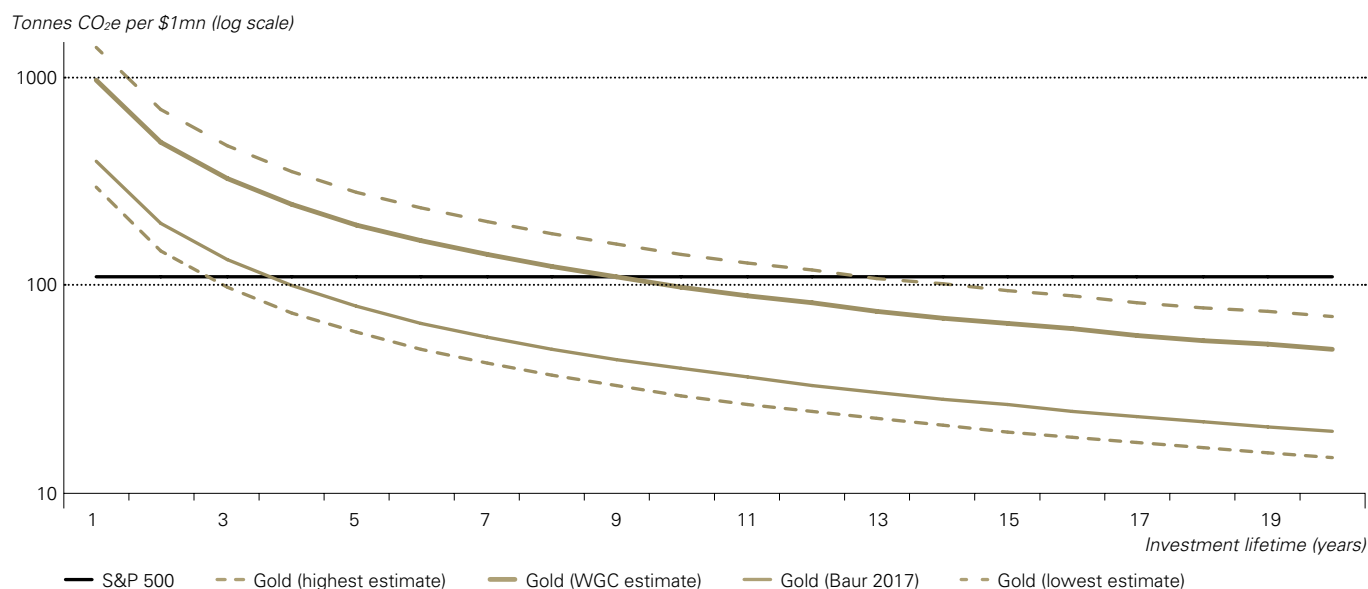
In the case of gold, the annual GHG emissions vary very significantly over its lifetime. The emissions from mining, milling, concentrating, smelting and refining are high; after this, however, emissions associated with the transport and storage of newly-mined gold as an investment, over its lifetime, are low. Baur & Oll therefore argue that total emissions over the lifetime of gold will be approximately equal to emissions from mining, milling, concentrating, smelting and refining. To calculate annualised emissions of newly-mined gold in a portfolio over a specific period of time, we divide the total emissions by the investment lifetime – the number of years the investment is held before it is liquidated.

$$\text{Annualised GHG emissions of gold} = (\text{Total GHG emissions} / \text{Number of years investment is held})$$

This is likely to over-estimate the annualised GHG emissions of gold since it effectively allocates the full GHG emissions to the initial investor. It also assumes that gold assets are wholly backed by newly-mined gold whereas this is highly unlikely in practice given the plentiful above-ground stocks of gold, the significance of recycled gold as a source of supply, and a product lifetime for bullion of many decades and even centuries.

The results of this analysis are presented in **Chart 9**, below, using the range of estimates of the GHG intensity of gold, and the emissions intensity of the S&P 500 presented by Baur & Oll. It shows that, using our best estimate, if an investor holds an investment in newly-mined gold for nine years or more, the annualised GHG footprint of the investment is lower than the annual GHG footprint of an equivalent-value investment in the S&P 500. Using the lowest estimate, this is true after just three years, and even using the highest estimate we have found in the literature, the footprint of gold will still be lower than that of the S&P 500 over an investment window of 13 years or more.

Chart 9: Estimated annualised GHG footprint of an investment in gold and S&P 500 over different investment lifetimes



Note: This does not depict estimates of the future emissions profile of gold production or of the S&P 500. Rather, the chart illustrates the annual GHG footprint of a US\$1mn investment in the S&P 500, and compares this with the GHG footprint of a US\$1mn investment in gold, quantified on an annualised basis over different investment lifetimes, and with a range of emissions intensity estimates for gold. Range values for gold are based on high and low estimates of the GHG emissions intensity per tonne of gold as reported in academic literature.

Source: WGC analysis based on Baur & Oll (2017)

This suggests that, when lifetime GHG emissions of gold are allocated across each year of a medium-to-long term investment period, investing in gold will likely reduce the overall GHG footprint of an investment portfolio also comprised of the S&P 500.

We therefore agree with Baur & Oll when they conclude that, “adding gold to an S&P500 portfolio promotes the sustainability of a portfolio.”

This is an area worthy of further research, with significant implications for investors seeking to lower the overall GHG footprint of their portfolios.

“Adding gold to an S&P500 portfolio promotes the sustainability of a portfolio.”

Baur & Oll, 2017

How exposed is gold to climate-related risks, and how might this compare to other sectors and asset classes?

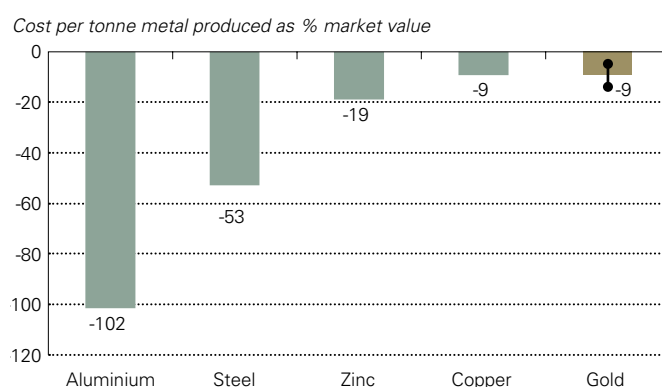
Looking forward, there are several reasons to believe gold may be less vulnerable to the physical and transition risks of climate change than other investment classes.

Firstly, we believe gold, as a finished product, is likely to face relatively limited physical risks from the impact of climate change. Gold is a highly pure, inert and robust metal. Unlike most other metals and natural resources, it is virtually indestructible and is not damaged over time or destroyed by the act of consumption. In consequence, nearly all the gold ever mined is still present and, theoretically, potentially available for re-use. Even in the event of a natural disaster, the physical properties and value of gold make it highly recoverable. And relatively plentiful above-ground stocks of gold mean supply is potentially far less vulnerable than other mined products to shocks and disruptions that may result from physical climate change impacts.

There are good reasons to believe gold will be less exposed to the physical and transition risks of climate change than other potential investments.

Gold may also face lower transition risks than many other potential investments. One significant transition risk with implications for investors is the potential negative impact of carbon pricing¹⁸ on the economics of production and, hence, the likely returns from sectors of the economy. Using the estimates of GHG intensity and analysis of market value set out in the Gold and Greenhouse Gas Emissions section of this report we have estimated the cost per tonne of metal produced that would occur due to a hypothetical carbon price of US\$100 per tonne CO₂e, levied on finished metal. As can be seen in **Chart 10**, due to its high value per tonne, and therefore low carbon footprint per US\$ value, gold is much less exposed to the potential negative impacts of carbon pricing than other metals.

Chart 10: Cost of a carbon price of US\$100/tCO₂e as proportion of market value



Note: Range values for gold are based on high and low estimates of the GHG emissions intensity per tonne of gold as reported in academic literature

Source: Metals Focus; S&P Global Market Intelligence; World Steel Association & EIU; World Gold Council

Emissions data collated from a range of academic studies and trade association reports

¹⁸ Carbon pricing refers to sums that must be paid by producers – in the form of a tax or permit fee – for the right to emit one tonne of CO₂ into the atmosphere.

Investors concerned about the impact of climate change will need to understand how different sectors, beyond metals and mining, will be able to reduce GHG emissions. We believe production of finished gold may potentially be easier and more cost-effective to decarbonise than some other sectors of the economy. Research indicates that approximately 50-60% of the carbon footprint of gold comes from electricity use during mining, milling, concentrating and smelting.¹⁹ Electricity is now increasingly cost-effective to decarbonise due to the rapidly improving technology, economics, and reliability of renewables and storage. Looking forward, these costs are expected to continue to decrease at double-digit rates and to move in favour of renewables over fossil fuels:²⁰

- the costs of energy from solar, wind, and battery storage are all forecast to reduce by 50-70% by 2040
- solar and wind energy is already cheaper than new fossil-fuel generation in some parts of the world and is forecast to undercut new gas and coal from 2030.

The rate of decarbonisation of the gold sector may be faster than many other sectors of the economy.

As we have illustrated elsewhere in this report,²¹ leading responsible gold miners are actively taking steps to improve energy efficiency and move to renewable energy sources – with the potential to materially reduce the carbon footprint of gold. Delivering this potential requires significant continued commitment and action from the gold industry. Given the current scale of activity, the rate of decarbonisation of the gold mining industry is likely to be faster than many other sectors of the economy, including agriculture, aviation, chemicals, industrial processes and heating. Investors are therefore likely to view gold more favourably in comparison. Simultaneously, the gold mining industry continues to play an important role in supporting sustainable social and economic development in the countries and communities in which they operate.

Finally, regardless of how the transition to a low-carbon economy plays out, investors should expect increased levels of risk and volatility as the impacts of climate change, and society's response to it, unfold over the coming decades. Gold's ability to moderate market risk and enhance the overall risk-return profile of investment portfolios is well documented.²² We believe that gold is also able to moderate against climate risk. We expect it to continue to play a role as a 'safe haven' in a financial landscape that could become increasingly volatile because of climate change.

In conclusion, while recognising this report represents an initial analysis only, our findings suggest there may be good reasons for investors concerned about climate change to consider gold's role as a strategic asset, including the key findings that:

- our research indicates gold has a lower carbon footprint than other major mined products and is comparable with the world economy as a whole
- incorporating gold alongside equities (the S&P 500) over the medium-to-long term may reduce the carbon footprint of an investor's portfolio
- gold may be less exposed to the physical and transition risks related to climate change than other sectors
- gold can provide an effective hedge against the disruption and volatility that adapting to climate change is likely to bring to investment markets.

We expect gold to continue to play a role as a "safe haven" asset in a financial landscape that could become increasingly volatile because of climate change.

19 Norgate & Haque. *Using life cycle assessment to evaluate some environmental impacts of gold production*. *Journal of Cleaner Production*, Volume 29-30, 53, 2012.

20 Bloomberg New Energy Finance, *New Energy Outlook 2017*, 2017, <https://about.bnef.com/new-energy-outlook/>

21 See the 'Gold mining: taking action to reduce GHG emissions' section.

22 Michaud, Michaud & Pulvermacher. *Gold as a Strategic Asset*, 2006; Michaud & Michaud. *Gold as a strategic asset for European investors*, 2011; Mercer. *Gold As An Asset Class For Institutional Investors*, 2014; Artigas et al., *The relevance of gold as a strategic asset*, 2018.

Gold mining: taking action to reduce GHG emissions

Responsibly undertaken gold mining plays an important role in supporting sustainable development.

Responsible gold mining is conducted with respect for the environment and the human rights of employees, contractors and members of communities associated with mining activities. When coupled with good governance, it delivers benefits for host countries and local communities. It contributes to economic development through increasing prosperity, providing jobs, building skills and, through partnerships with governments and other actors, facilitating investment in infrastructure and public services.

Despite differing geographical, operational and regulatory challenges, World Gold Council Member companies are working towards reducing their greenhouse gas emissions.

Responsible gold mining companies take seriously their commitment to meet international standards, including reporting to the Carbon Disclosure Project (CDP).

Featured in this section are descriptions of a wide range of initiatives that are set to reduce GHG emissions in the coming years. The projects reported here represent a small sample of the endeavours currently being undertaken or planned by member companies of the World Gold Council as they seek to reduce their carbon footprint through improvements in energy efficiency and, where possible, transition to low carbon energy sources. These initiatives vary greatly in type and scale but share the objective of lowering CO₂e emissions and indicate the direction in which the industry is heading.

Significantly, many of the projects detailed here offer additional positive business impacts and substantial cost savings as well as a reduction in emissions.



Image courtesy of Agnico Eagle.

Borden: the ‘goldmine of the future’

Goldcorp’s Borden mine is set to become the world’s first all-electric underground gold mine. The mine will replace current diesel-fuelled mobile equipment with Battery Electric Vehicles (BEVs).

The investment in electric equipment at Borden will improve safety performance and annually reduce GHG emissions by 70% (6,600t of CO₂e). Electric engines are three times more efficient than their diesel equivalents and reduce megawatt hours (MWh) by 33,000 per year due to the huge decrease in ventilation requirements.

Over a 10-year period, this represents a reduction of close to 70,000t of CO₂e and 330,000 MWh in electricity.

With the decrease in emissions comes a reduction in underground ventilation needs, which will see Borden require 50% less ventilation than a baseline diesel underground mine.

The Borden underground mine will operate year-round on a continuous (24-hour) basis, at a rate of up to approximately 4,000t of ore per day when averaged over the year.



Borden electric underground mining vehicle. Image courtesy of Goldcorp.

Solar power transforms the Essakane mine in Burkina Faso

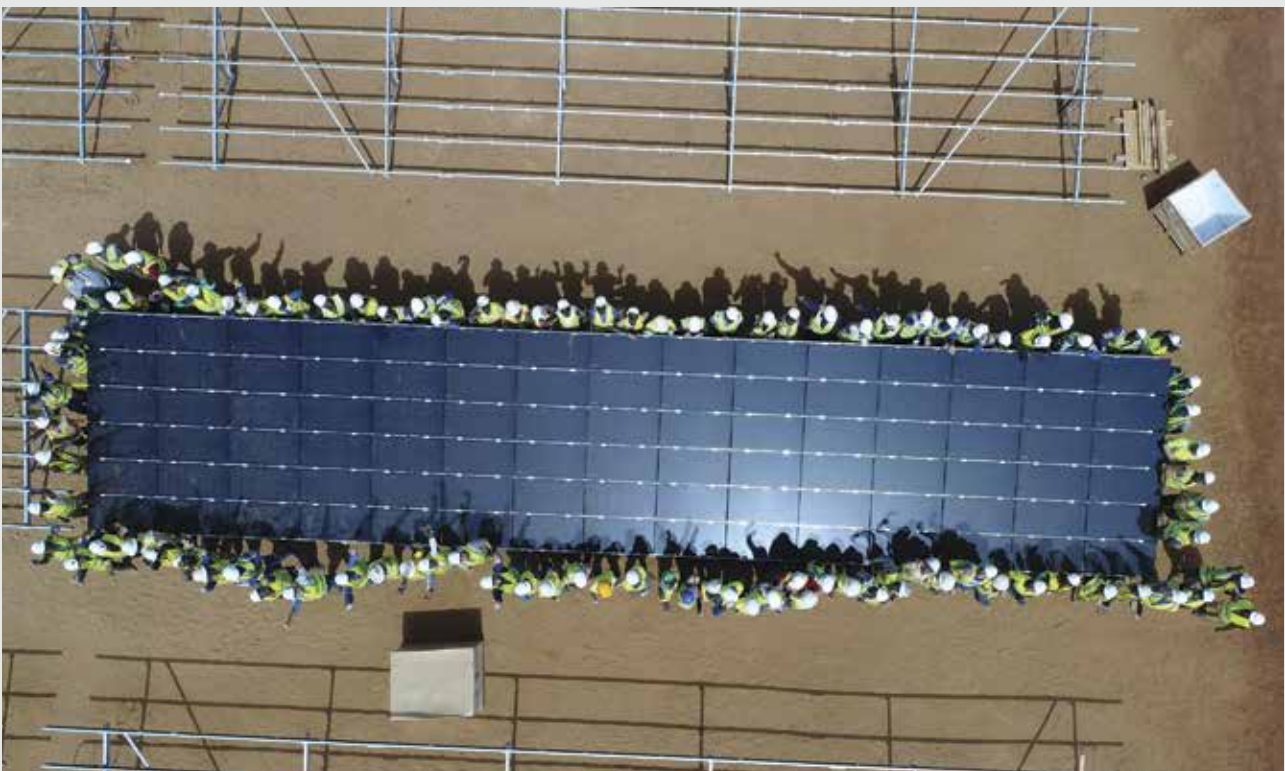
IAMGOLD's subsidiary, IAMGOLD Essakane SA, has partnered with Total Eren, AREN ENERGY (PTY) Ltd and Essakane Solar SAS to source electricity from a 15MWp (megawatt peak output) solar power plant to the company's Essakane mine in Burkina Faso. The agreement is for an initial period of up to 15 years and will help the company reduce its environmental footprint and electricity costs.

The project will allow integration of a solar plant into the mine's existing 57MW HFO (heavy fuel oil) power plant, making it, at the time of construction, the world's biggest hybrid HFO-solar power plant. Essakane Solar will act as owner of the solar plant during the length of the contract, while IAMGOLD Essakane SA will act as a single buyer by purchasing all the energy produced. The inauguration of the first third of the solar plant took place on 16 March 2018.

The solar plant covers an area of 22 hectares on the mine's site. Approximately 130,000 photovoltaic modules are installed on the plant. On a yearly basis,

the fuel oil consumption will be reduced by approximately 6mn litres, representing a reduction of about 18,500t of CO₂ emissions. The capital cost of the project is US\$25mn.

In addition to reducing the environmental impact and cost of electricity at the mine, the solar plant brings the key benefit of local employment. About 100 local workers have been employed during the construction phase of the project and 40 more will be employed during the whole operation phase of the plant. One per cent of revenues generated by Essakane Solar SAS will be invested in community projects around the mine. These projects will be identified and implemented in partnership with local authorities.



Installation of solar panels at Essakane. Image courtesy of IAMGOLD.

Using science based targets, carbon pricing, and fuel switching to lower emissions

Newmont is working to evaluate longer term, science-based emission targets for its global operations as well as determining the types of actions that would be required to achieve these targets.

These targets include increasing renewable energy supply through self-generation or power purchase agreements as well as transitioning to electric and/or electric-hybrid vehicles.

A key success thus far has been expanding the use of fuel efficiency technologies, such as the Blutip solution Newmont implemented at its Boddington operation, which has reduced diesel fuel consumption by 5.2% and GHG emissions by 10,000t on an annual basis.

In addition, fuel switching to lower emissions sources has been a vital component to Newmont's 2020 emission reduction goal, and a key example for this is Newmont's Tanami Power project.

In early 2017, extreme weather in Australia's Tanami desert led to widespread, sustained flooding. For two months, diesel, which is the primary fuel source for the mine, could not be trucked into the site. As a result, production – at an average of 8,000 ounces of gold per week – was shut down during the month of February.

To improve energy security and mitigate climate change risk, Newmont conducted a review of options including an analysis of the cost of carbon, giving the company greater visibility into each option's embedded carbon risk and exposure to future carbon pricing schemes.

The price of carbon was analysed at US\$25 and at US\$50 per tonne of carbon dioxide equivalent (CO₂e). These price points were based on current carbon pricing used by mining and energy companies.

The review resulted in Newmont approving the Tanami Power project, including the construction of a 280-mile long (450 kilometres) natural gas pipeline, which is set to deliver a consolidated energy solution for the mine by providing reliable, gas-fuelled power generation. Switching from diesel fuel to natural gas is expected to reduce annual energy costs and carbon emissions by approximately 20% beginning in 2019.

In addition, in 2017, Newmont established a target to reduce its GHG emissions intensity by 16.5% by the end of 2020, measured from a base year of 2013. To date, Newmont has achieved a 15.6% reduction, with the company on track to achieve an additional 1% reduction by the end of 2020.



Tanami mine. Image courtesy of Newmont Mining.

Optimised underground ventilation system reduces energy consumption and emissions

Barrick's goal is to reduce its greenhouse gas emissions by 30% by 2030 from a 2016 baseline. Currently, 36% of the Barrick's electricity comes from renewable sources. It is deploying a number of initiatives to reduce overall GHG levels, including the evaluation of moving to a lower emission fuel at its power plant in the Dominican Republic and designing future mines to include electric and automatic equipment.

The business impact of the reduction in energy demand, consumption and GHG emissions is evident at Barrick's Hemlo mine in Canada. Hemlo developed a site-wide ventilation management programme to facilitate continuous improvement and spur innovation in technology, people and systems. As a result, Hemlo was able to drive down energy consumption and GHG emissions by optimising its underground ventilation system. It implemented ventilation on demand (VOD) in targeted areas of the mine and fans without VOD were managed exclusively by trained personnel.

Hemlo also reduced heating costs by taking advantage of the mine's naturally-occurring geothermal properties. The mine was able to draw fresh air via the stopes in old mining areas to create an air supply that did not need heating in winter, whereas in summer, ice stopes cooled the air. Energy consumption as measured by ventilation per tonne of ore fell from 96.7 kilowatt hours per tonne (kWh/t) in 2013 to 86.1kWh/t in 2015; a reduction of 24% in GHG emissions and a decrease of 10% in energy consumption over two years.

In recognition of this innovative approach to conserving energy, in 2016 Canada's Department of Natural Resources awarded Hemlo the 'Process and Technology Improvement Award.'

Since 2016, mining operations at Hemlo have expanded but the mine has been able to maintain similar levels of energy intensity, demonstrating the enduring impact of these innovative solutions.



Hemlo mine. Image courtesy of Barrick.

Reducing GHG by hydropower and optimisation of haulage conditions

Kinross is constantly reviewing its energy supply matrix in order to identify opportunities to reduce both costs and emissions. It has recently acquired two hydroelectric power plants (155MW installed capacity) in Brazil that will ensure sustainability of a renewable energy supply for its Paracatu operation.

Fuel for mining operations represents the largest category of direct emissions. There is an intense focus on optimisation of haulage conditions and driver training as these produce fuel savings, cost reductions and reduced emissions. Route optimisation work at the Bald Mountain mine in Nevada has saved more than 15,000 hours of haulage time since January 2017, while at the Fort Knox mine in Alaska time savings of over 10% have been made on every haul truck cycle

to the heap leach pads. The operators of haul trucks are trained with simulators to develop optimum driving skills that economise on fuel consumption.

Kinross is currently implementing a number of capital projects too, incorporating energy efficiency into the design of its operations from the onset. These energy management projects are set to contribute to further GHG savings.



Driving simulators help optimise fuel use. Image courtesy of Kinross.

Hydropower results in mine's low GHG footprint

Centerra Gold's Kumtor mine, a large-scale mining operation in the Kyrgyz Republic, is a significant consumer of fuel and electricity. Fuel represents over 20% of the mine's overall commodity and service related purchases. Kumtor's most energy intensive operation is its mill, representing approximately 75% of the mine's electricity consumption.

The Kyrgyz Republic is a leading producer and exporter of hydroelectric energy in the Central Asia region, thanks to its mountainous terrain and abundant water resources. Hydropower generates more than 70% of the country's electricity.

The major source of power supplied to Kumtor is from the Toktogul Reservoir located on the Naryn River. This means that the mine's specific GHG emission footprint resultant from electricity is relatively low. Centerra Gold aims to further reduce GHG intensity by lowering its energy consumption and increasing energy efficiency.

Where and when feasible, the company is switching from diesel generators to grid electricity, thus gaining the greatest value from its initiatives to reduce emissions. Its actions lower both the mine's costs and GHG footprint.



Kumtor mine. Image courtesy of Centerra Gold.

Automatic compressed air control reduces energy consumption

In 2016, AngloGold Ashanti's Vaal River mine won the 'Project of the Year' award from the South African Association for Energy Efficiency for its Vaal River Compressor Real-time Dynamic Control System (REMS-DCS).

The Vaal River mining complex consumes 250 megawatt hours (MWh) per day for the supply of compressed air. The intricate network consists of 37MW of installed compressors along a 27km surface piping network, with multiple users situated on the surface and underground. To reduce energy consumption, and thereby reduce its carbon footprint by 4,400 tons of CO₂ per annum, AngloGold Ashanti implemented a real-time dynamic control system (REMS-DCS) to optimise and automate its compressor controls.

The project achieved an energy reduction of 1.65MW during the evening peak period and realised an annual saving of approximately US\$140,000, although the total savings from multiple parallel projects on compressed air efficiency amount to almost twice this sum.

Full automatic compressed air control on this magnitude has never previously been achieved in the mining environment.



Automatic air compressor at Moab Khotsoeng mine. Image courtesy of AngloGold Ashanti.

Gold's role as a key component in low-carbon technologies

Gold is an important and widely utilised industrial metal. During 2017, 333t of gold were used in technical applications, a 3% increase on 2016 figures.

While the electronics sector is the dominant source of this demand, recent technical advances have begun to reveal new uses for gold.

Of particular relevance in the context of mitigating climate change, gold in a nanoparticulate form has considerable potential in a range of applications that can help reduce GHG emissions.

Catalysing a cleaner future

Catalysis is vital to 'green chemistry' – chemical products and processes that reduce or eliminate the use or impact of hazardous substances. One of the most exciting emerging technologies in the use of catalysts relates to the capture and conversion of carbon.

Despite its importance, catalysis is not a particularly well understood branch of science and technology. The production of almost all industrial chemicals rely on catalysts. Precious metals are commonly used in chemical catalysis. They make excellent catalysts because they

are chemically 'pliable', meaning that they interact with the starting materials and solvents within the chemical reaction while being relatively stable to heat and pressure. This gives them longevity: a fundamental characteristic of an efficient catalyst.

Precious metals are already used extensively in catalytic converters for vehicles, removing large amounts of pollutants generated by diesel and petrol engines. These converters can operate efficiently for many years in the harsh environment of a car's exhaust system. In 40 years of R&D, only precious metals have been shown to be capable of delivering these results over extended periods of time.

The availability of efficient catalysts is becoming increasingly important in an emerging area of science and technology known as carbon capture and use (CCU). According to recent research by McKinsey, CCU could reduce annual GHG emissions by as much as one billion metric tonnes in 2030 if a handful of key technologies are successfully and rapidly developed.²³



Synthesised gold nanoparticles.

“Captured carbon dioxide can technically be converted into virtually any type of fuel or chemical that is otherwise derived from petroleum. The question is how to do this economically enough so that the resulting fuels and chemicals are cost-competitive with those derived from oil.”

McKinsey & Company, 2018

²³ Biniek et al., *Why commercial use could be the future of carbon capture*. McKinsey & Company, 2018.

The promise of converting carbon dioxide into useful fuels is heavily dependent upon the electrochemical carbon dioxide reduction reaction (CO₂RR). Recently, there has been considerable research into developing new catalysts that can selectively and efficiently convert CO₂ into fuels with steady operation for hundreds of hours. One of the most promising of these is based on gold. A recent discovery of gold nanostructured catalysts by researchers at the University of Toronto²⁴ represents a significant advance in the field and has paved the way for selective and efficient CO₂ reduction to carbon monoxide (CO), a precursor to synthetic fuels.

The nanostructured gold catalyst is shaped in a needle just a few microns thick. When supplied with electrical potential, the gold nanoneedle catalyst converts CO₂ into CO with high activity and selectivity. Once the carbon monoxide has been produced, it can be combined with hydrogen gas to make syngas, a precursor to many fuels such as gasoline.

The US Government's National Energy Technology Laboratory (NETL) is also heavily involved in the search for advanced clean-tech catalysts. Researchers have developed a special engineered form of nanoparticle catalyst composed of 25 atoms of gold, which has shown considerable potential for use in the carbon dioxide reduction reaction.²⁵ Indeed, the researchers believe that renewable energy sources, such as wind and solar, could power large scale CO₂ conversion plants in the future, effectively providing a potential route to a carbon-negative energy cycle.

Many start-up companies are focused on the commercialisation of these technologies. They join established chemical companies such as Siemens and Evonik, who recently demonstrated sustained and large-scale CO₂ conversion to alcohols.²⁶ A considerable number of academic groups and start-ups are also involved in the NRG COSIA Carbon XPrize, which is a US\$20mn grand prize challenge seeking technologies that can capture and convert CO₂ into a valuable product. The nanostructured catalysts pioneered by the Sargent Lab at the University of Toronto are represented in the final of the grand challenge, where they will be scaled up from the laboratory (a few milligrams per hour) to a micro-pilot unit capable of producing hundreds of kilograms per day.

While a number of catalysts are being considered, the current evidence suggests that gold is the best-in-class catalyst for the highly active and selective reduction of CO₂ to CO.

A recent discovery of gold nanostructured catalysts by researchers at the University of Toronto represents a significant advance in the field and has paved the way for selective and efficient CO₂ reduction to carbon monoxide (CO), a precursor to synthetic fuels.

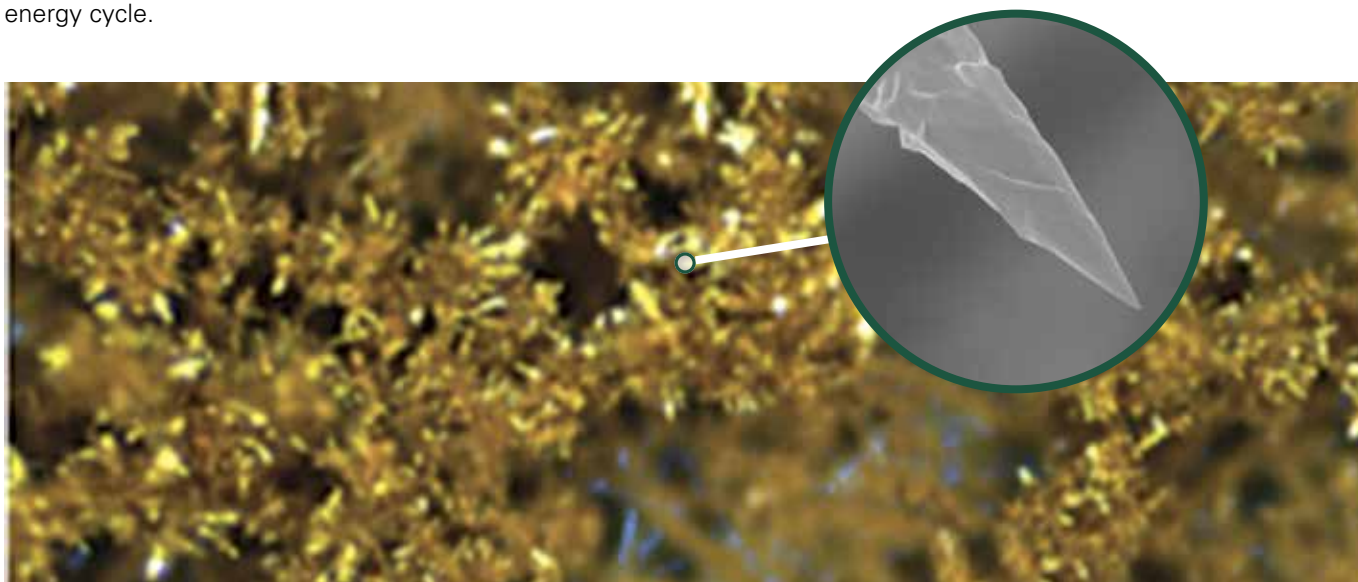


Image of the gold nanoneedle catalyst and zoomed in electron micrograph of the nanostructured surface of the gold nanoneedles. Courtesy of Phil De Luna & The Sargent Lab, University of Toronto.

24 Liu et al., *Enhanced electrocatalytic CO₂ reduction via field-induced reagent concentration*. *Nature*, 537, 7620, 382, 2016.

25 Kauffmann et al., *Efficient electrochemical CO₂ conversion powered by renewable energy*. *ACS applied materials & interfaces*, 7, 28, 15626, 2015.

26 Haas et al., *Technical photosynthesis involving CO₂ electrolysis and fermentation*. *Nature Catalysis*, 1, 32, 2018.

Driving the next generation of fuel cells

A fuel cell produces electricity via a chemical reaction without the need for combustion. The electricity is created through the combining of hydrogen and oxygen; critically the only other product of this reaction is water. As with the carbon dioxide reduction reaction, an efficient catalyst material is required to lower the energy required to synthesise water, a relatively stable chemical entity. Catalysts in fuel cells typically contain platinum, but recent research suggests significant improvements can be made by incorporating gold nanomaterials. Fuel cells need a pure stream of hydrogen to operate efficiently, requiring a catalyst which operates effectively at low temperature. A recent study published in the leading journal *Science* highlights how gold nanoclusters can be used to efficiently remove small quantities of carbon monoxide (CO) from the hydrogen stream. This is important because CO acts as a poison, lowering the efficiency of the fuel cell reaction. The study suggests this specific gold nanoparticle catalyst is one of the first materials identified that can fulfil this role, and holds considerable promise for a range of industrially important applications.²⁷

Another recent study has utilised gold in combination with other metals to create a catalyst that is several times more efficient than platinum alone.²⁸ This represents a significant step towards making and discovering new particle catalysts for almost any industrially important process.

“We combined theory, a powerful new tool for synthesizing nanoparticles and more than one metallic element – in this case, an alloy consisting of platinum, copper and gold – to create a catalyst that is seven times more active than state-of-the-art commercial platinum.”

Chad A. Mirkin, the George B. Rathmann Professor of Chemistry in the Weinberg College of Arts and Sciences and the Director of the International Institute for Nanotechnology at Northwestern University



Image ©Rob Crandall/Shutterstock.com

27 Yao et al., *Atomic-layered Au clusters on α -MoC as catalysts for the low-temperature water-gas shift reaction*. *Science*, DOI: 10.1126/science.aah4321, 2017.

28 Huang et al., *Catalyst design by scanning probe block copolymer lithography*. Huang et al. *PNAS*, <https://doi.org/10.1073/pnas.1800884115>.

Improving photovoltaics

Beyond their considerable promise as catalysts, gold nanomaterials are of growing interest to scientists as a potential route to improving how the sun's energy can be captured and utilised. Gold has a long association with glazing, having often been used as a thin coating on glass to improve energy efficiency in buildings. Its excellent infrared shielding capability helps to reduce the significant levels of heating incurred by large glazing footprints, thus lowering energy costs within the building itself. Modern technologies are gradually seeing this approach evolve, increasingly utilising gold nanoparticles to drive improvements. Recently, scientists at Imperial College London developed a material that can turn a transparent surface into a reflective one when an electric current is applied.²⁹

This opens up the opportunity to integrate 'smart windows' into new buildings, where self-shading can potentially actively regulate temperature, limiting GHG emissions generated from traditional inefficient heating and cooling patterns.

Gold has also been incorporated into a variety of experimental solar cell devices. Work is now underway to integrate these into buildings directly, taking the smart window concept a step further. Perovskite cells, widely seen as one of the most promising new solar cell technologies, can utilise gold electrodes in their modules and efforts are underway to incorporate nanomaterials within the cells to further improve power generation efficiencies.³⁰

Gold nanomaterials are of growing interest to scientists as a potential route to improving how the sun's energy can be captured and utilised.



Image ©Thongsuk Atiwannakul/Shutterstock.com

²⁹ Montelongo et al., *Electrotunable nanoplasmonic liquid mirror*. *Nature Materials*, 16, 1127, 2017.

³⁰ Zhang et al., *Efficient perovskite solar cells by combination use of Au nanoparticles and insulating metal oxide*. *Nanoscale*, 9, 2852, 2017.

Conclusions and areas for future work

This report, representing the World Gold Council's initial research into gold and climate change, has set out our estimates of the GHG footprint of gold, based on currently available data and conservative assumptions.

Our initial findings confirm that, whilst there is limited published data on gold's global carbon footprint, total GHG emissions from newly-mined gold are significantly lower than those from other major metals and mined products. When analysed on a 'per US\$ value' basis, gold has amongst the lowest emissions intensity of all metals and mined products.

We have also explored some of the implications of these findings for investors focused on better understanding the climate change risks and opportunities in their portfolio holdings.

Additionally, we have shown that leading gold miners are taking action to reduce GHG emissions. And we have considered how gold can play a role in new technologies that can help address climate change.

We recognise, however, that much work remains to be done to gain a clearer, more consistent and comprehensive view of the climate change impacts of the gold sector. This report has highlighted important gaps in the available data and addressing these would be of significant benefit to all stakeholders. Like all sectors of the economy, the gold industry faces the challenge of defining a pathway that will enable a reduction in greenhouse gas emissions in line with the goals of the Paris Agreement, whilst considering wider sustainable social, environmental and economic development goals.

Below are potential future areas of work that we believe would be of value to further inform this dialogue and support investors in making informed decisions when considering gold as an asset class in the light of climate change considerations.

Area	Potential future work
Continue to develop increasingly robust data on the GHG footprint of gold	• Source improved and more comprehensive estimates of the Scope 1 and Scope 2 GHG emissions of finished gold, such as: – estimates covering a wider proportion of global gold production and range of different mining and production locations and methods – longitudinal data sets – quantifying in detail the impact of recycling on the GHG footprint of finished gold. • Develop estimates of Scope 3 emissions, focusing on emissions from downstream uses and applications.
Implications and tools for investors	• Develop tools to support the investment community as it considers gold as an asset class in the context of climate change, to include: – comparing the lifetime GHG footprint with a wider comparative set (e.g. other equity indices and asset classes) – longitudinal data sets and sensitivity analysis – in-depth analysis of the physical and transition risks related to investments in gold and how these may compare with other sectors and asset classes.
Explore emissions reduction pathways in line with achieving the goals of the Paris Agreement	• Develop a sector/category view of potential emissions reductions pathways. This might include: – scenarios setting out potential pathways for emissions reduction and understanding how these align with wider sustainability criteria, including the UN Sustainable Development Goals – defining overall science-based targets for the sector to deliver emissions reductions consistent with achieving the goals of the Paris Agreement – marginal abatement cost curves for the range of emissions reduction opportunities.

Appendix – detailed methodology

In this report, we have estimated the GHG emissions intensity of the production of finished gold from primary mine supply. We have used our estimate of emissions intensity, along with data on global production of finished gold from primary mine supply, to estimate the total GHGs emitted.

Our estimate of the GHG emissions intensity is derived from a thorough review of the existing literature. This includes data from six peer-reviewed academic studies,^{31–36} as well as our own analysis of the GHG emissions publicly reported by mining companies. We did not commission any new primary analysis.

In terms of boundaries, our analysis aligns with the academic studies and mining companies' reports. We include Scope 1 and Scope 2 emissions from the processes of mining, milling, concentrating, smelting and refining to produce finished gold. Comparisons with other metals and mined products are made on the same basis, again based on existing publicly available literature and sources. We have not considered Scope 3 emissions and, in particular, have not looked at emissions from the end use of finished gold products. We have also not examined emissions from the recycling of existing gold products (or waste products containing gold).

The GHG emissions intensity of finished gold production varies as a function of the specific circumstances of production. The major factors that drive variation in emissions intensity include:

- ore type and grade
- processing technology
- mine type – underground or open pit
- geographic location.

Two of the academic studies^{37–38} provide different estimates for the GHG intensity of gold, depending on whether production is based on refractory or non-refractory ores. We have calculated a weighted average emissions intensity for each of these studies, based on an estimated proportion of 33% refractory and 67% non-refractory ores, as cited in two recent studies.^{39–40}

The results of our review are set out in **Chart 11**. This shows the estimates of the GHG emissions intensity from the peer-reviewed studies.

31 Norgate & Haque. *Using life cycle assessment to evaluate some environmental impacts of gold production*. *Journal of Cleaner Production*, Volume 29-30, 53, 2012.

32 Mudd. *Global trends in gold mining: Towards quantifying environmental and resource sustainability*. *Resources Policy*, 32, 1–2, 42, 2007.

33 Hageluku & Meskers. *Complex Life Cycles of Precious and Special Metals. Chapter 10, Linkages of Sustainability*. Edited by Thomas E. Graedel and Ester van der Voet. 2010.

34 Haque & Norgate. *The greenhouse gas footprint of in-situ leaching of uranium, gold and copper in Australia*. *Journal of Cleaner Production*, 84, 382, 2014.

35 Nuss P, Eckelman MJ. *Life Cycle Assessment of Metals: A Scientific Synthesis*. *PLoS ONE*, 2014 doi:10.1371/journal.pone.0101298.

36 Chen et al., *Life cycle assessment of gold production in China*. *Journal of Cleaner Production*, 179, 143, 2018.

37 Norgate & Haque. *Using life cycle assessment to evaluate some environmental impacts of gold production*. *Journal of Cleaner Production*, Volume 29-30, 53, 2012.

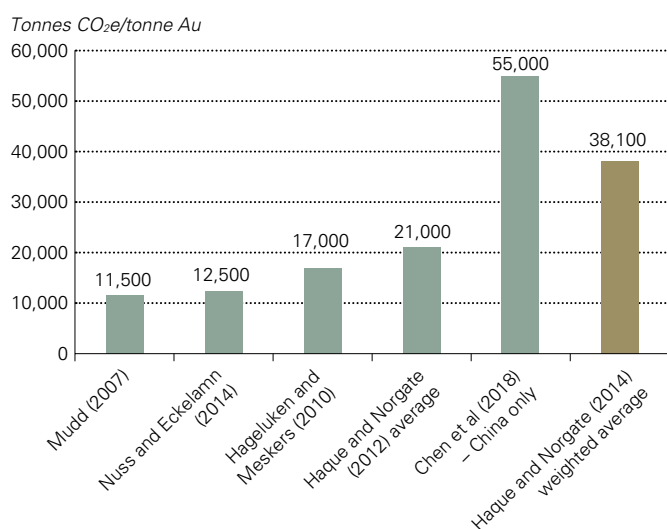
38 Hageluku & Meskers. *Complex Life Cycles of Precious and Special Metals. Chapter 10, Linkages of Sustainability*. Edited by Thomas E. Graedel and Ester van der Voet. 2010.

39 Yang et al., *A selective process for extracting antimony from refractory gold ore*. *Hydrometallurgy*, 169, 571, 2017

40 Li et al., *Improvement of Gold Leaching from a Refractory Gold Concentrate Calcine by Separate Pretreatment of Coarse and Fine Size Fractions*. *Minerals*, 7, 80, 2017.

Based on this data, and in discussion with expert researchers at the Centre for Environmental Policy at Imperial College London, we estimate the emissions intensity of the production of finished gold to be 38,137t CO₂e/tAu (rounded to 38,100 t CO₂e/tAu within the report). This is based on the most recent study by Haque & Norgate,⁴¹ experts based at the renowned Australian research institution CSIRO,⁴² which considers both refractory and non-refractory ore at a grade of 2g per tonne. We believe this represents the best available estimate for the value of the emissions intensity of gold in a peer-reviewed study. This estimate is at the highest end of the range of academic studies that have looked at gold on a global basis.

Chart 11: Estimates of the emissions intensity of gold



It should be noted that, as this paper used only open access sources and did not undertake primary research, the average ore grade used in the calculation of gold's GHG emissions intensity was a conservative one. Current data on ore grades from both open-pit and underground gold mines suggests a considerably higher global average ore grade might be appropriate and this suggests a further avenue for additional research.

Nonetheless, we recognise that there are a wide range of different estimates of GHG emissions intensities in the literature. This reflects both the relative lack of data available compared to some other sectors, and the specific circumstances and considerations of the studies, for example:

- 1 A recent paper looking at Chinese gold production (Chen et al. 2018) presented an average estimated emissions intensity of 55,000t CO₂e/tAu. This is the highest estimate we have seen in the literature and we understand that this is primarily due to significant amounts of coal-based electricity generation used in China.⁴³ The paper does not suggest that this figure is representative of gold production worldwide.
- 2 An earlier study (Mudd 2007) presents an estimated emissions intensity of 11,500t CO₂e/tAu. This figure is perceived by experts as unlikely to be fully representative of the current typical emissions intensity for gold, not least as the study was based around relatively higher gold ore grades. As noted above, the issue of how ore grades will impact on emissions calculations is an area that deserves further investigation.

Given the wide range of estimates in the academic literature, we believe it is appropriate to reference these in our analysis. We therefore present all emissions intensities and derived calculations, centred around a 'core' estimate of the GHG emissions intensity (38,100t CO₂e/tAu), and an upper and lower range representing the highest and lowest figures in the literature (55,000t CO₂e/tAu and 11,500t CO₂e/tAu, respectively).

41 Hageluken & Meskers. *Complex Life Cycles of Precious and Special Metals. Chapter 10, Linkages of Sustainability*. Edited by Thomas E. Graedel and Ester van der Voet. 2010.

42 Commonwealth Scientific and Industrial Research Organisation (CSIRO), an independent agency of the Australian Federal Government responsible for scientific research in Australia, <http://www.csiro.au/>

43 The high Chinese emissions intensity figures deserve further analysis in the light of recent environmental regulations – e.g. the 'Environmental Protection Law of the People's Republic of China' of 2015 and the 'Gold Industry Clean Production Evaluation Standard' of 2016 – which are already having a material impact on gold production.

Glossary

Base metals: These metals are broadly defined as those that oxidize, tarnish or corrode relatively easily when exposed to air or moisture. They are often relatively abundant in nature and sometimes easier to mine. They are also often widely used in commercial and industrial applications such as construction and manufacturing. Base metals, including aluminium, copper, lead, nickel, tin and zinc, are often described as “nonferrous”, meaning they contain no iron. Typically, they are far less expensive than precious metals such as gold, silver and platinum that are much rarer and may require significant mining resources to extract in any meaningful quantity.

Bulk metals: Metals that are relatively common and widely used. In this report, we use this term as a broad descriptor to include both iron and non-ferrous ‘base’ metals.

Carbon Capture & Use (CCU): A new branch of science and technology focused on the capture and transformation of CO₂ into commercially viable products such as bio-oils, chemicals, fertilisers and fuels.

Carbon Footprint: The term ‘carbon footprint’ is used to mean the total mass of greenhouse gas emissions caused by an organisation, product or process over a given time period. A carbon footprint considers all seven of the Kyoto Protocol greenhouse gases: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sodium hexafluoride (SF₆), nitrogen trifluoride (NF₃), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

CO₂e: ‘CO₂e’ or ‘carbon dioxide equivalent’ is a unit of measurement of greenhouse gases that allows the different gases to be compared on a like-for-like basis relative to one unit of CO₂. For a given mass of a specific greenhouse gas, CO₂e represents the mass of CO₂ that would have the same global warming impact over a specified number of years (most commonly 100 years). CO₂e is calculated by multiplying the mass of each non-CO₂ greenhouse gas by its 100-year global warming potential. For example, methane (CH₄) has a 100-year global warming potential of 28.⁴⁴ Therefore 1 tonne of methane is equivalent to 28t of CO₂e.

Global warming potential: An index measuring the global warming impact following an emission of a unit mass of a given greenhouse gas, accumulated over a chosen time period, relative to that of the reference gas, carbon dioxide (CO₂). The global warming potential represents the combined effect of the differing times these gases remain in the atmosphere and their effectiveness in causing global warming.

Greenhouse gases: The Kyoto Protocol includes seven key greenhouse gases emitted by human activities that contribute to anthropogenic climate change, including carbon dioxide, methane, nitrous oxide and fluorinated gases.

HFO: Heavy Fuel Oil or ‘residual fuel oil’ is the high viscosity, tar-like mass that remains after distillation of crude oil, commonly used for marine diesel engines and for burning in furnaces, boilers and lanterns.

kW: Kilowatt: a unit for measuring power that is equivalent to one thousand watts.

kWh: Kilowatt hour: the kilowatt hour is a unit of energy equivalent to one thousand watts expended for one hour of time.

Low carbon economy: An economy based on low carbon power sources that therefore has a minimal output of GHG emissions into the biosphere, but specifically refers to CO₂.

MW: Megawatt: a unit for measuring power that is equivalent to one million watts. One MW is roughly equivalent to the energy produced by 10 automobile engines.

MWh: Megawatt hour: the megawatt hour is a unit of energy equivalent to one million watts of power expended for one hour of time.

MWp: Megawatt peak output: a metric of the maximum output of a photovoltaic power device or plant.

⁴⁴ Intergovernmental Panel on Climate Change, *Fifth Assessment Report (AR5)*, http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf

Primary gold supply: This refers to the supply of gold from the mining process. For the purpose of this report, the primary gold mining process has been split into four key activities:

- 1 Mining: the process of extracting gold-containing ore from the ground, using explosives and heavy machinery.
- 2 Milling: grinding the ore into smaller particles to improve recovery rates.
- 3 Concentrating and smelting: separating the gold from the crushed ore by chemical leaching, followed by purifying to Dore bars (60-90% pure gold) using heat.
- 4 Refining: the final purification step to 24 carat gold.

Nanotechnology: The study and application of materials containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1nm (nanometre) – 100nm.

Recycling: The process of recovering gold via re-refining. Approximately 25-30% of demand is met by recycled gold, primarily from the jewellery industry.

Renewable energy (or renewables): Energy that is collected from renewable resources that are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat.

United Nations Sustainable Development Goals: The UN Sustainable Development Goals (SDGs), otherwise known as the Global Goals, are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity.

Copyright and other rights

© 2018 World Gold Council. All rights reserved. World Gold Council and the Circle device are trademarks of the World Gold Council or its affiliates.

All references to LBMA Gold Price are used with the permission of ICE Benchmark Administration Limited and have been provided for informational purposes only. ICE Benchmark Administration Limited accepts no liability or responsibility for the accuracy of the prices or the underlying product to which the prices may be referenced. Other third party content is the intellectual property of the respective third party and all rights are reserved to them.

Reproduction or redistribution of any of this information is expressly prohibited without the prior written consent of World Gold Council or the appropriate copyright owners, except as specifically provided below.

The use of the statistics in this information is permitted for the purposes of review and commentary (including media commentary) in line with fair industry practice, subject to the following two pre-conditions: (i) only limited extracts of data or analysis be used; and (ii) any and all use of these statistics is accompanied by a citation to World Gold Council and, where appropriate, to Thomson Reuters or other identified third party source, as their source.

World Gold Council does not guarantee the accuracy or completeness of any information. World Gold Council does not accept responsibility for any losses or damages arising directly or indirectly from the use of this information.

This information is not a recommendation or an offer for the purchase or sale of gold, any gold-related products or services or any other products, services, securities or financial instruments (collectively, "Services"). Investors should discuss their individual circumstances with their appropriate investment professionals before making any decision regarding any Services or investments.

This information contains forward-looking statements, such as statements which use the words "believes," "expects," "may," or "suggests," or similar terminology, which are based on current expectations and are subject to change. Forward-looking statements involve a number of risks and uncertainties. There can be no assurance that any forward-looking statements will be achieved. We assume no responsibility for updating any forward-looking statements.



Pulps used to produce this paper are Elemental Chlorine Free (ECF).

The paper mill and printer are accredited to ISO14001 environmental standards.

World Gold Council
10 Old Bailey, London EC4M 7NG
United Kingdom
T +44 20 7826 4700
F +44 20 7826 4799
W www.gold.org